Note on the use of Long-focus Mirrors for Eclipse work.

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1. At recent eclipses the inner corona has been successfully photographed on a large scale with long-focus lenses: lengths of 40 feet, 60 feet, and even 100 feet do not seem to be unmanageable. Such lenses are naturally costly, and it is of interest to inquire how far they can be replaced by concave mirrors, which are cheaper.

2. It may be taken for granted that any telescope of such a focal length must be used in conjunction with a cœlostat, or some form of heliostat which allows the telescope to remain fixed in position. We may therefore disregard at present any disadvantages which are introduced by the cœlostat itself, and exist whether we use a refracting or reflecting telescope—such, for

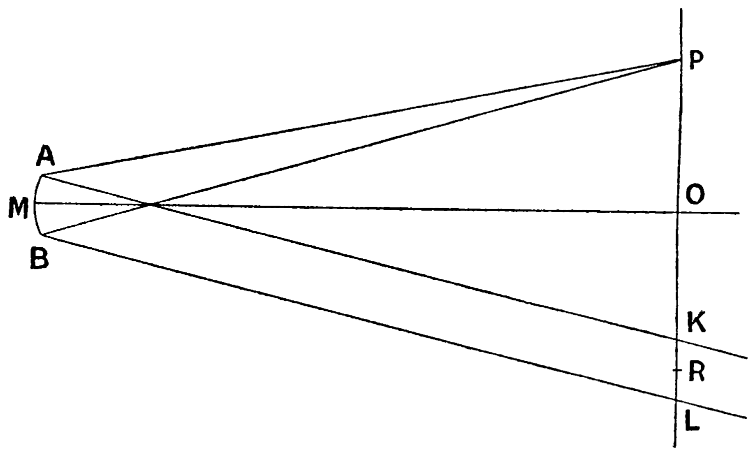

Fig. 1.

instance, as the want of perfect flatness in the plane mirror. But there is an important difference between the two cases in respect of the available field, which it is the object of the present Note to briefly elucidate. Practically there is no difficulty about the field with a lens, unless it be placed unnecessarily far away from the cœlostat (see *Monthly Notices*, lvi. p. 413).

3. As regards the mirror. Let A B (fig. 1) be the concave mirror, centre M and axis M O; and P any point in the image formed in the focal plane. If we trace the rays backwards from P to the mirror, and then towards the origin of light, they will form a sensibly circular cylinder which cuts the focal plane in a circle K L sensibly equal to the mirror, and having its centre at R, where O R = O P. For ideal definition at the point P this cylinder of rays must all fall on the cœlostat mirror, otherwise only a portion of the concave will be used in forming the image at P. But in practice we shall be able to put up with something

short of this; how much short of it remains to be determined, probably by actual experiment.

4. As we move P about to different portions of the image, R moves about over a precisely similar path, carrying the circular patch K L with it. And for ideal definition at all points of the image, the total area thus indicated must fall on the cœlostat mirror. Thus we can find the size and shape of the smallest cœlostat mirror which must be used in the focal plane, when we know the contour of the image. *Or conversely*, if we know the size and shape of the mirror we can find the contour of the image within which there will be ideal definition.

5. It is more convenient to consider the problem from this latter point of view, for the effective shape of the mirror (*i.e.* its projection on the focal plane) will usually be an ellipse. For a circular mirror of radius a placed near the focus of the concave, and inclined at an angle θ to the focal plane, the axes of this ellipse are $2a$ and $2a \cos \theta$; or, say, $2a$ and $2b$. In fig. 2 let X Y be this ellipse, and let a circle with centre R and radius c equal to

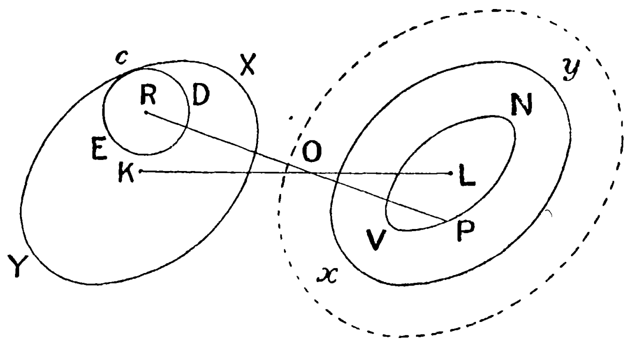

FIG. 2.

the radius of the concave mirror touch X Y internally. As R moves about, keeping this circle in contact with the ellipse, its image P will describe the contour of the image formed by the whole concave, and it is easily seen that this contour is an oval curve of axes $2(a-c)$ and $2(b-c)$. Thus unless the cœlostat mirror is so large that

$$a \cos \theta > c$$

then no part of the image will get light from all parts of the concave. But we can of course always cut down the concave by a diaphragm to secure this condition.

6. If we are satisfied with the rays from about *half* the concave mirror, then we can always get an available image equal in size and shape to the ellipse X Y. For if R lie on the edge of X Y, half the circle surrounding it (a little more indeed) will fall outside X Y, but the remaining portion will lie within; and the image formed at P will still be as good as (say) a heliometer image, which uses half the object glass. As R moves round the edge of X Y, P will describe a precisely similar ellipse

xy; and within this ellipse, which is equal in size and shape to the projection X Y of the cœlostat mirror, we accordingly get a fair image. A larger oval found by making R move so that the circle CDE touches X Y externally gives the limit of any image at all.

7. To fix the ideas, suppose that the cœlostat mirror is 16 inches in diameter and is inclined at an angle of 45° to the incident beam; so that $2a = 16$ inches, $2b = 11{\cdot}3$ inches. Then with a concave of 12 inches diameter we shall get no field at all filled by the whole mirror; but if we cut the aperture of the concave down to 8 inches we get an oval field 8 inches long and 3·3 inches wide filled by the whole mirror. If we do not cut the 12-inch mirror down we get *more light* at every point of the image, but this light comes from a non-circular mirror. It is a question which can be worked out theoretically, but will probably be more easily settled experimentally, how far the extra light got from a large concave is a gain?

8. One point seems clear. If we place the image of the eclipsed Sun centrally we shall lose the best part of the image in the central part obscured by the Moon. To make clear what is meant by central let us recur to fig 2. The important axis for us is the line joining K, the centre of the cœlostat, to the centre of the concave mirror, which cannot be represented in this figure—call it M, as in fig. 1. It is the line K M which forms the central ray, reflected along M L to the centre of the image. The normal M O to the concave mirror is only of secondary importance. Keeping M fixed, we may tilt the concave mirror and thus move O about to any point in the plane represented by fig. 2, carrying the point L and the patches surrounding it to positions represented by the law of images, *i.e.* K O = O L always. And if the dark centre of the Sun is viewed from M in the cœlostat in the direction of MK, the image of the dark centre will be formed at L, the best part of the field. Hence we must clearly arrange to see in the direction MK a part of the corona, which can be then photographed at L.

9. Before leaving the concave, remark that we cannot pass from one part of the corona to another by tilting it. Whatever part can be seen from M in the cœlostat (in the direction M K) is reflected to L, which should be the centre of the plate; and by tilting the concave we merely select a different position for putting the plate. At the same time we alter the angle of incidence on the concave of the field we are photographing; and since it is important to have this as small as possible, the proper tilt of the concave is immediately indicated—viz. it should be such that the line KOL is in the direction of the minor axis of X Y: and O should be as near to K as is possible without cutting off any portion of the image which it is wished to keep. When the concave is fixed in accordance with these conditions, the proper position for the plate is also fixed.

10. But we may, during the eclipse, alter the position of the cœlostat slightly in R A, and thus bring different parts of the corona into the field. We will consider this point presently.

11. Let us first get some sort of an idea how much of the corona can be photographed at once. The diameter of the Moon with different focal lengths is as follows :—

Diameter in inches	8	12	16
Focal length in feet	69	104	138

Thus even with a concave of 140 feet focus we could, with a 16-inch cœlostat, photograph about half the corona at once, if we are content with light from about half the concave mirror over some portions of the image. The definition will vary in quality in different parts of the image, the amount of variation depending on the size of the concave mirror. With shorter focal lengths we get more of the corona at a single exposure; with longer focal lengths less. But as the focal length increases the angle of incidence diminishes, and the portion which is photographed will therefore be better photographed.

12. Thus with a concave of 140 feet focus and a 16-inch cœlostat we could bring one limb of the Sun central during the early part of totality and take photographs of it; then, using the slow motion of the cœlostat in R A, bring the other limb central and photograph that. Note that the cœlostat is close to the observer and he could easily manage to do this, or to superintend it, and the position for plates is not altered. The two limbs would not necessarily be either the R A or N P D limbs, being determined entirely by the direction of the minor axis of the ellipse which represents the cœlostat mirror. Portions of the limb 90° away from these would suffer most from defective definition and loss of light.

13. It seems to me possible, though I have not at the moment time to examine the point, that these portions of the corona might be brought central by tilting the cœlostat mirror in N P D—*i.e.* inclining it slightly to the polar axis. Such a tilt is of course an error in adjustment, and produces a slow change in the image, but the change might not be serious enough to matter under the circumstances of an eclipse.

14. One small point may be noticed in conclusion. If such mirrors are used, the photographs taken will not be suitable for determining the relative brightness of different parts of the corona without a troublesome calculation of the amount of light received by different parts of the image.